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LIMBACH & LIMBACH L.L.P.
2001 Ferry Building, San Francisco, CA 94111
415/433-4150

Address to:
Box Patent Application
Assistant Commissioner for Patents
Washington, D.C. 20231

Attorney's Docket No. SONY-T0665

First Named Inventor SHIRO OMORI

UTILITY PATENT APPLICATION TRANSMITTAL
(under 37 CFR 1.53(b))

SIR:

Transmitted herewith for filing is the patent application entitled:
SIGNAL PROCESSING APPARATUS, METHOD OF THE SAME, AN IMAGE PROCESSING APPARATUS AND METHOD OF THE SAME

CERTIFICATION UNDER 37 CFR § 1.10

I hereby certify that this New Application and the documents referred to as enclosed herein are being deposited with the United States Postal Service on this date June 1, 2000, in an envelope bearing "Express Mail Post Office To Addressee" Mailing Label Number EL059097980US addressed to: Box Patent Application, Assistant Commissioner for Patents, Washington, D.C. 20231.

Elizabeth Reicker — Elizabeth Reicker
(Name of person mailing paper) (Signature)

Enclosed are:

1. X Transmittal Form (two copies required)

2. The papers required for filing date under CFR § 1.53(b):
   i. 58 Pages of specification (including claims and abstract);
   ii. 12 Sheets of drawings.
   __ formal x informal

3. Declaration or oath

   a. x Unsigned

ACCOMPANYING APPLICATION PARTS

4. __ An assignment of the invention to Sony Corporation is attached (including Form PTO-1595).

   i. __ 37 CFR 3.73(b) Statement (when there is an assignee)

5. x Power of Attorney (unsigned)

6. __ An Information Disclosure Statement (IDS) is enclosed, including a PTO-1449 and copies of __ references.

7. X Preliminary Amendment and Letter to Official Draftsperson

8. X Return Receipt Postcard (MPEP 503 -- should be specifically itemized)

9. __ Other

10. FOREIGN PRIORITY
   [x] Priority of application no. P11-157431 filed on June 4, 1999 in Japan is claimed under 35 USC 119.

   The certified copy of the priority application:
   x is filed herewith; or
   _ has been filed in prior application no. _ filed on _, or
   _ will be provided.

__ English Translation Document (if applicable)

11. **FEE CALCULATION**

a. __ Amendment changing number of claims or deleting multiple dependencies is enclosed.

CLAIMS AS FILED

	Number Filed	Number Extra	Rate	Basic Fee ($690)
Total Claims	16 - 20	* 0	x $18.00	0
Independent Claims	8 - 3	* 5	x $78.00	390.00
__ Multiple dependent claim(s), if any			$260.00	0

*If less than zero, enter "0".

Filing Fee Calculation $1,080.00

50% Filing Fee Reduction (if applicable) . . . . $

12. Small Entity Status
   a. __ A small entity statement is enclosed.
   b. __ A small entity statement was filed in the prior nonprovisional application and such status is still proper and desired.
   c. __ is no longer claimed.

13. Other Fees
   __ Recording Assignment [$40.00] $0
   __ Other fees
   Specify ____________________ $0

Total Fees Enclosed $1,080.00

14. Payment of Fees
   x Check(s) in the amount of $ 1,080.00 enclosed.
   __ Charge Account No. 12-1420 in the amount of $__.
   A duplicate of this transmittal is attached.

15. All correspondence regarding this application should be forwarded to the undersigned attorney:

Charles P. Sammut
Limbach & Limbach L.L.P.
2001 Ferry Building
San Francisco, CA 94111
Telephone: 415/433-4150
Facsimile: 415/433-8716

16. Authorization to Charge Additional Fees

X The Commissioner is hereby authorized to charge any additional fees (or credit any overpayment) associated with this communication and which may be required under 37 CFR § 1.16 or § 1.17 to Account No. 12-1420. **A duplicate of this transmittal is attached.**

LIMBACH & LIMBACH L.L.P.

June 1, 2000
(Date)

By: ______________________
Charles P. Sammut
Registration No. 28,901
Attorney(s) or Agent(s) for Applicant(s)

Attorney Docket No. SONY-T0665
[S00P0665US00]

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of	)	Group Art Unit: Unknown
SHIRO OMORI ET AL.	)	Examiner: Unknown
Application No. Not Assigned	)	PRELIMINARY AMENDMENT
Filed: Herewith	)	2001 Ferry Bldg. San Francisco, CA 94111 Ph.: 415-433-4150
For: SIGNAL PROCESSING APPARATUS, METHOD OF THE SAME, AN IMAGE PROCESSING APPARATUS AND METHOD OF THE SAME	)	

Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

Prior to examination of the above-identified application, please enter the following amendments:

In the Specification

Page 12, line 11, please change "Fig. 1 is a view" to --Figs. 1A, 1B, 1C, 1D and 1E are views--;

Page 12, line 21, please change "Fig. 4 is a view" to --Figs. 4A, 4B, and 4C are views--;

Page 13, line 13, please change "Fig. 10 is a view" to

--Figs. 10A, 10B, and 10C are views--;

Page 13, line 18, please change "Fig. 12 is a view" to --Figs. 12A, 12B, 12C, 12D, 12E,and 12G are views--;

In the Drawings

With the permission of the Examiner, as set forth in the attached LETTER TO OFFICIAL DRAFTSPERSON, please amend the drawings as follows:

Please relabel the lowermost "FIG.10A" as --FIG.10B--.

Please relabel the rightmost "FIG.12F" as --FIG.12G--.

REMARKS

The amendments to the specification and drawings are to conform the drawings to the specification, to conform the specification to the drawings and/or correct typographical errors. It is respectfully submitted that such amendments are supported by the specification, claims, abstract of the disclosure and the drawings.

The Examiner's early examination and consideration are respectfully requested.

Respectfully submitted,
LIMBACH & LIMBACH L.L.P.

By: ______________________
Charles P. Sammut
Reg. No. 28,901

June 1, 2000
Our File: SONY-T0665

SIGNAL PROCESSING APPARATUS, METHOD OF THE SAME, AN IMAGE PROCESSING APPARATUS AND METHOD OF THE SAME

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a signal processing apparatus and method using a difference in sampling phase for removing aliasing components and to thereby broaden the frequency band of a signal and an image processing apparatus and method for processing an image signal obtained by capturing a plurality of images having a predetermined difference in sampling phase by a single imaging element.

2. Description of the Related Art

In the related art, there has been a signal processing method in a charged coupled device (CCD) or other image sensor for obtaining a broad band image doubled in the number of pixels by inputting two images shifted by a pitch of exactly half of the sampling interval and up-sampling and adding the two. The signal processing method is applicable to a black and white CCD image sensor, triple-element RGB CCD image sensor, etc.

Also, there have been attempts to apply this to an image obtained by a single-element CCD image sensor

having a color filter, currently the mainstream in video cameras and still image pickup devices (hereinafter also referred to as electronic still cameras). Since a single-element CCD image sensor has a color filter cycle of, for example, every two pixels etc., it has been considered to shift images by half of the cycle, that is, one pixel. A signal of an image captured by a single-element CCD image sensor and converted from an analog to digital format is processed in a later camera signal processor to generate an RGB signal or a luminance signal and a color difference signal using interpolation for each color or an interrelationship among the colors.

Summarizing the problem to be solved by the invention, in a single-element CCD image sensor, however, when shifting the pixels, the array of signals of the colors becomes different from the conventional array due to the increase in the number of pixels. The later camera signal processor therefore not only has to process an increased number of pixels, but also has to change the algorithm itself.

Also, when shifting the pixels by less than the pixel pitch of the CCD image sensor, there is the disadvantage that the camera signal processor has to process a signal with uneven sampling, so the processing becomes complex.

For example, when using a Bayer array single-element CCD image sensor obtaining a R (red), G (green), and B (blue) pixel array pattern shown in Fig. 12A to obtain a total of four images shifted one pixel each in the vertical, horizontal, and diagonal directions, the obtained pixel arrays of the R, G, B data become as shown in Figs. 12E, 12F, and 12G, which are different from the normal pixel arrays shown in Figs. 12B, 12C, and 12D.

Namely, as will be understood by comparing Figs. 12C and 12D with Figs. 12F and 12G, the numbers of samples of R data and B data are increased four times, while as is understood by comparing Fig. 12B and Fig. 12E, the number of samples of G data is only doubled.

Therefore, the camera signal processor has to process R, G, B data of the pixel arrays shown in Figs. 12E, 12F, and 12G, so there is the disadvantage that the processing becomes complex.

Also, when shifting an image by less than the pixel pitch, the sampling intervals become uneven, so there is the disadvantage that the processing becomes difficult.

SUMMARY OF THE INVENTION

An object of the present invention is to provide an image processing apparatus and method capable of

obtaining a high resolution image from a low resolution image without making the processing in the camera signal processor complex and a signal processing apparatus and method using the band broadening method used in the image processing apparatus etc.

To attain the above object, according to a first aspect of the present invention, there is provided a signal processing apparatus comprising a transforming means for transforming a plurality of first digital signals having mutually different sampling phases to generate a plurality of second digital signals in frequency domain; a memory means for storing a plurality of complex numbers corresponding to the sampling phases; and a processing means for multiplying the plurality of second digital signals and the plurality of complex numbers corresponding to the plurality of second digital signals and adding the multiplication results to generate a third digital signal free from aliasing components.

In the signal processing apparatus of a first aspect of the present invention, the transforming means transforms the plurality of first digital signals having mutually different sampling phases a plurality of second digital signals in the frequency domain.

Then, the processing means multiplies the plurality of second digital signals with a plurality of complex

numbers stored in the memory means corresponding to the plurality of second digital signals and adds the multiplied results to generate third digital signals freed from aliasing components.

Preferably, the apparatus further comprises a phase shift means for shifting the phase of the first digital signals or the second digital signals by exactly a predetermined phase.

According to a second aspect of the present invention, there is provided a signal processing apparatus, comprising a phase shift means for shifting the phase of a plurality of first digital signals having mutually different sampling phases to generate second digital signals; a memory means for storing a plurality of real numbers indicating real parts and imaginary parts of a plurality of predetermined complex numbers corresponding to the sampling phases; a processing means for multiplying the first digital signals with real numbers indicating the real parts corresponding to the first digital signals to obtain first multiplied results, multiplying the second digital signals corresponding to the first digital signals with real numbers indicating the imaginary parts corresponding to the second digital signals to obtain second multiplied results, and adding the first multiplied results and the second multiplied

results to generate third digital signals free of aliasing components.

According to a third aspect of the present invention, there is provided an image processing apparatus, comprising an image input means for generating a plurality of first image signals having mutually different sampling phases in accordance with imaging results; a transforming means for transforming the first image signals to a frequency domain to generate a plurality of second image signals; a memory means for storing a plurality of complex numbers corresponding to the sampling phases; a processing means for multiplying the plurality of second image signals with the plurality of complex numbers corresponding to the plurality of second image signals and adding the multiplied results to generate third image signals free from aliasing components.

Preferably, the image input means forms an image of a plurality of color lights passed through a single-plate type color filter on corresponding pixels among a plurality of pixels arranged in a matrix two-dimensionally to generate the first image signals comprised by color data of the plurality of colors; and the processing means performs the multiplication and the addition for every color data of the plurality of color

data to generate a plurality of fourth image signals corresponding to the plurality of colors and generates the third image signals by using the plurality of fourth image signals.

More preferably, the sampling phase is determined for a predetermined one color among the plurality of colors in order that a sampling pattern of color data of the color included in the plurality of first image signals and a sampling pattern of color data included in the fourth image signals of the color become similar.

Preferably, the processing means comprises a spatial shift means for spatially shifting the second image signals in accordance with the sampling phases; a basic spectrum calculation means for multiplying the spatially shifted plurality of second image signals with the plurality of complex numbers corresponding to the plurality of second image signals and adding the multiplied results to calculate a basic spectrum free from aliasing components; and an inverse transforming means for transforming the basic spectrum from a frequency domain to a time domain to generate the third image signals.

Alternatively, preferably the apparatus further comprises a drive means for moving the image input means physically, optically, or electrically so that the image

input means can generate a plurality of image signals having mutually different sampling phases in accordance with the imaging results.

Alternatively, more preferably the image input means is a single-element CCD image sensor and the color filter is a primary color filter or a color compensation filter.

According to a fourth aspect of the present invention, there is provided an image processing apparatus, comprising an image input means for receiving as input a plurality of first image signals having mutually different sampling phases in accordance with imaging results; a phase shift means for shifting the phase of the plurality of first digital signals to generate second digital signals; a memory means for storing a plurality of real numbers respectively indicating real parts and imaginary parts of a plurality of predetermined complex numbers corresponding to the sampling phases; a processing means for multiplying the first digital signals with real numbers indicating the real parts corresponding to the first digital signals to obtain first multiplication results, multiplying the second digital signals corresponding to the first digital signals with real numbers indicating the imaginary parts corresponding to the second digital signals to obtain second multiplied results, and adding the first

multiplied results and the second multiplied results to generate third digital signals free from aliasing components.

According to a fifth aspect of the present invention, there is provided a signal processing method comprising transforming a plurality of first digital signals having mutually different sampling phases to a frequency domain to generate a plurality of second digital signals; multiplying the plurality of second digital signals with a plurality of complex numbers corresponding to the plurality of second digital signals; and adding the multiplied results to generate third digital signals free from aliasing components.

According to a sixth aspect of the present invention, there is provided a signal processing method using a plurality of real numbers indicating real parts and imaginary parts of a predetermined plurality of complex numbers corresponding to sampling phases, comprising shifting a plurality of first digital signals having mutually different sampling phases by predetermined phases to generate second digital signals; multiplying the first digital signals with real numbers indicating the real parts corresponding to the first digital signals to generate first multiplied results; multiplying the second digital signals corresponding to

the first digital signals with real numbers indicating the imaginary parts corresponding to the second digital signal to generate second multiplied results; and adding the first multiplied results and the second multiplied results to generate third digital signals free of aliasing components.

According to a seventh aspect of the present invention, there is provided an image processing method comprising generating a plurality of first image signals having mutually different sampling phases in accordance with imaging results; converting the first image signals to a frequency domain to generate a plurality of second image signals; and multiplying the plurality of second image signals with a plurality of complex numbers corresponding to the plurality of second image signals and adding the multiplication results to generate third image signals free from aliasing components.

Preferably, the method further comprises forming an image of a plurality of color lights passing through a single-plate type color filter on corresponding pixels among a plurality of pixels arranged in a matrix two-dimensionally to generate the first image signals comprised by color data of the plurality of colors and performing the multiplication and the addition for every color data of the plurality of colors to generate a

plurality of fourth image signals corresponding to the plurality of colors and generate the third image signals by using the plurality of fourth image signals.

More preferably, the method further comprises determining the sampling phase for a predetermined one color among the plurality of colors so that a sampling pattern of color data of the color included in the plurality of first image signals and a sampling pattern of color data included in the fourth image signals of the color become similar.

According to an eighth aspect of the present invention, there is provided an image processing method using a plurality of real numbers prepared in advance indicating real parts and imaginary parts of a predetermined plurality of complex numbers corresponding to sampling phases, comprising generating a plurality of first image signals having mutually different sampling phases in accordance with imaging results; shifting by a predetermined phase the plurality of first digital signals to generate second digital signals; multiplying the first digital signals with real numbers indicating the real parts corresponding to the first digital signals to generate first multiplied results; multiplying the second digital signals corresponding to the first digital signals with real numbers indicating the imaginary parts

corresponding to the second digital signals to generate second multiplied results; and adding the first multiplied results and the second multiplied results to generate third digital signals free of aliasing components.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects and features of the present invention will become clearer from the following description of the preferred embodiments given with reference to the accompanying drawings, in which:

Fig. 1 is a view for explaining an RGB Bayer array single-element CCD image sensor used in an electronic still camera of a first embodiment of the present invention;

Fig. 2 is a view of a part of the configuration of the electronic still camera of the first embodiment of the present invention;

Fig. 3 is a view for explaining a sampling phase of four images captured by a CCD image sensor shown in Fig. 2 for obtaining one high resolution image;

Fig. 4 is a view for explaining processing in a signal processor shown in Fig. 2;

Fig. 5A is a view for explaining a sampling phase of R data to be processed in a signal processor shown in Fig. 2 and Fig. 5B is a view for explaining a sampling

phase of B data to be processed in the signal processor shown in Fig. 2;

Fig. 6 is a view of the configuration of the signal processor shown in Fig. 2;

Fig. 7 is a view of a part of the configuration of an electronic still camera of a second embodiment of the present invention;

Fig. 8 is a view of the configuration of a signal processor shown in Fig. 7;

Fig. 9 is a view of a part of the configuration of an electronic still camera of a third embodiment of the present invention;

Fig. 10 is a view for explaining a color compensating filter used in the CCD image sensor shown in Fig. 9;

Fig. 11 is a view of the configuration of a signal processor shown in Fig. 9; and

Fig. 12 is a view for explaining disadvantages of the related art.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Below, an electronic still camera according to the present embodiments will be explained.

First Embodiment

An electronic still camera of the present embodiment

is provided with an RGB Bayer array single-mode CCD image sensor and processes four sets of RGB data different in sampling phases obtained by the CCD image sensor using a predetermined band broadening method to increase the resolution and thereby obtain RGB data having a double bandwidth corresponding to double the number of pixels vertically and horizontally.

Specifically, the electronic still camera obtains G data, R data, and B data of the pixel arrays shown in Figs. 1B, 1C, and 1D from the four sets of RGB data different in sampling phase, including the RGB data of the pixel array shown in Fig. 1A, and add these to obtain the RGB data of the pixel array shown in Fig. 1E.

Figure 2 is a view of a part of the configuration of an electronic still camera of the present embodiment.

As shown in Fig. 2, the electronic still camera 1 comprises a lens 2, an optical LPF 3, a CCD image sensor 4, an AD converter 5, a CCD drive 6, a memory 7, a signal processor 8, and a camera signal processor 9.

[Optical LPF 3]

The optical LPF 3 is an optical low pass filter (LPF) for removing unnecessary high band components from light from the object being photographed passing through the lens 2.

[CCD 4]

The CCD image sensor 4 comprises a plurality of photodiodes arranged in a matrix and a Bayer color filter array. The Bayer color filter array is comprised of G (green) color filters arranged in a checkerboard pattern and R (red) filters and B (blue) filters arranged in a checkerboard pattern in the remaining parts. The photodiodes receive light passing through the Bayer color filter array and convert the light to electrical signals to generate received light signals $S4_0$ to $S4_3$ 4 in accordance with the amount of received light and outputs the received light signals $S4_0$ to $S4_3$ to the AD converter.

The CCD image sensor 4 is, as will be explained later on, driven to move by the CCD drive 6 and captures four images different in sampling phases for obtaining a single high resolution image.

[AD Converter 5]

The AD converter 5 converts the received light signals $S4_0$ to $S4_3$ to image signals $S5_0$ to $S5_3$ and outputs an image signal S5 to the signal processor 8.

[CCD Drive 6]

The CCD drive 6 physically moves the CCD image sensor 4 by exactly a predetermined distance in a predetermined direction based on a control signal S8a from the signal processor 8 so that the CCD image sensor

4 captures a total of four images respectively having phases of (0, 0), (π/2, -π/2), (0, π), (π/2, π/2) when assuming sampling intervals of the CCD image sensor 4 to be 2π and the phase of one image to be the origin (0, 0) as shown in Fig. 3.

The signal processor 8 uses the image signal S5 of the four captured images having mutually different sampling phases as shown in Fig. 3 input from the AD converter 5 to generate an image signal S8b of an image having double the number of pixels in the vertical and horizontal directions.

Here, the image signal S5 is composed of the pixel data of pixels arranged in the matrix constituting the CCD image sensor 4. Pixel data of pixels at positions indicated by "G" in Fig. 4A indicate G (green) data, pixel data of pixels at the positions indicated by "R" in Fig. 4B indicate R (red) data, and pixel data of pixels at the positions indicated by "B" in Fig. 4C indicate B (blue) data.

The signal processor 8 writes the image signal S5 of the four captured images input from the AD converter 5 in the memory 7, then reads it out and processes the image signal S5 by a later explained band broadening method to generate an image signal S8b so as to generate R data and B data of the pixel array patterns shown in Figs. 1C and

1D from R data and B data of the pixel array patterns shown in Figs. 4B and 4C.

Note that the pixel array pattern of G data shown in Fig. 4A and the pixel array pattern of G data shown in Fig. 1B are the same, so no processing is necessary for the G data. Namely, the signal processor 8 uses the G data included in the image signal S5 as it is as the G data of the image signal S8b.

Also, the signal processor 8 generates a control signal S8a based on information on the direction of movement and distance of the CCD image sensor 4 stored in the memory 7 in advance so as to obtain four captured images having mutually different sampling phase shown in Fig. 3 and outputs the control signal S8a to the CCD drive 6.

Below, the processings for generating R data and B data of the image signal S8b in the signal processor 8 will be explained.

Note that the processings for generating R data and B data are the same except for the value of the sampling phase.

Here, the "sampling phase" indicates the coordinates of a pixel corresponding to pixel data of a certain color included in the image signal S5 of the four captured images when assuming the position of a certain pixel

corresponding to pixel data of that color included in the image signal S8b to be the origin.

Specifically, for the R data, the sampling phases of the four captured images, as shown in Fig. 5A, respectively become $(\alpha_{x0}, \alpha_{y0})=(\pi/2, 0)$, $(\alpha_{x1}, \alpha_{y1})=(\pi, -\pi/2)$, $(\alpha_{x2}, \alpha_{y2})=(\pi/2, \pi)$, and $(\alpha_{x3}, \alpha_{y3})=(\pi, \pi/2)$.

Also, for the B data, the sampling phases of the four captured images, as shown in Fig. 5B, respectively become $(\alpha_{x0}, \alpha_{y0})=(0, \pi/2)$, $(\alpha_{x1}, \alpha_{y1})=(\pi/2, 0)$, $(\alpha_{x2}, \alpha_{y2})=(0, 3\pi/2)$, and $(\alpha_{x3}, \alpha_{y3})=(\pi/2, \pi)$.

The values of these sampling phases are used as $(\alpha_{x0}, \alpha_{y0})$ to $(\alpha_{x3}, \alpha_{y3})$ at the time of the later explained spatial shifting and are stored in the memory 7 shown in Fig. 2 in advance.

Figure 6 is a view of the configuration of the signal processor 8.

As shown in Fig. 6, the signal processor 8 comprises an interpolation circuit 50, a Fourier transform circuit 51, a spatial shift circuit 52, a basic spectrum calculation circuit 53, and an inverse Fourier transform circuit 54.

The interpolation circuit 50 receives as inputs image signals $S5_0$ to $S5_3$ of the four captured images to obtain one high resolution image, interpolates these and up-samples them two-fold to generate image signals $S50_0$

to $S50_3$, and outputs the image signals $S50_0$ to $S50_3$ to the Fourier transform circuit 51.

Specifically, the interpolation circuit 50 inserts (M_x-1) number of "0's" between the sampling positions in the x direction and (M_y-1) number of "0's" between the sampling positions in the y direction for the image signals $S5_0$ to $S5_3$ to generate the image signals $S50_0$ to $S50_3$.

Note that M_x and M_y are multiples indicating how many multiples of frequency components for restoration to in the x direction and y direction with respect to the Nyquist frequency. In the present embodiment, both are "2".

The Fourier transform circuit 51 converts the image signals $S50_0$ to $S50_3$ input from the interpolation circuit 50 to generate image signals $S51_0$ to $S51_3$ of a frequency domain expression and outputs the image signals $S51_0$ to $S51_3$ to the spatial shift circuit 52.

The spatial shift circuit 52 performs two-dimensional spatial shifting on the R data and B data included in the image signals $S51_0$ to $S51_3$ obtained by imaging to generate image signals Y_0 to Y_3 to express that sampling was performed in the positions of Figs. 4B and 4C.

Namely, the spatial shift circuit 52 multiplies R

data and B data of the image signals $S51_0$ to $S51_3$ with $\exp(-j(\omega_x\ \alpha_{x0}+\omega_y\ \alpha_{y0})/(2\pi))$ to $\exp(-j(\omega_x\ \alpha_{x3}+\omega_y\ \alpha_{y3})/(2\pi))$, respectively, to generate image signals Y_0 to Y_3.

Note that, at this time, the portion above the Nyquist frequency indicates negative frequencies both in the x direction and y direction. The ωx or ωy in this portion has to be made $(\omega_x-\omega_{sx})$ or $(\omega_y-\omega_{sy})$. Here, ω_{sx} and ω_{sy} respectively are sampling frequencies in the x direction and y direction before up-sampling.

The basic spectrum calculation circuit 53 uses the image signals Y_0 to Y_3 input from the spatial shift circuit 52 and complex numbers w_0 to w_3, w_0' to w_3' stored in the memory 7 shown in Fig. 2 to separately generate the two-dimensional image signals $X_{0,0}$ of the R data and B data and outputs the image signal S53 comprised of the generated image signals $X_{0,0}$ of the R data and B data and the G data of a pixel in the position shown in Fig. 4A to the inverse Fourier transform circuit 54.

Note that the memory 7 stores, for each of the R data and B data generated as explained later, the complex numbers w_0 to w_3 to be multiplied with the image signals Y_0 to Y_3 for finding the basic spectrum components $X13_{0,0}$ in the first and third quadrants and the complex numbers w_0' to w_3' to be multiplied with the image signals Y_0 to Y_3 for finding the basic spectrum components $X24_{0,0}$ of the

second and fourth quadrants.

The basic spectrum calculation circuit 53 obtains basic spectrum components $X13_{0,0}$ not containing aliasing components based on the formula (1) below and obtains basic spectrum components $X24_{0,0}$ not containing aliasing components based on the formula (2) below:

$$X13_{0,0} = \frac{1}{4}\left\{(1-j)Y_0 + (1+j)Y_1 + (1-j)Y_2 + (1+j)Y_3\right\} \quad \ldots(1)$$

Here, (1-j),(1+j),(1-j) and (1+j) in the formula (1) are defined as w_0, w_1, w_2 and w_3 respectively.

$$X24_{0,0} = \frac{1}{4}\left\{(1+j)Y_0 + (1-j)Y_1 + (1+j)Y_2 + (1-j)Y_3\right\} \quad \ldots(2)$$

Here, (1+j),(1-j),(1+j) and (1-j) in the formula (2) are defined as w_0', w_1', w_2' and w_3' respectively.

Then, as shown in formula (3) below, the basic spectrum components $X13_{0,0}$ and $X24_{0,0}$ are added to generate the basic spectrum component $X_{0,0}$.

$$X_{0,0} = X13_{0,0} + X24_{0,0} \quad \ldots(3)$$

Below, the grounds of the above formulas (1) and (2) will be explained.

First, the theory behind the band broadening method

using a plurality of discrete signals having differences in sampling phase in a two-dimensional direction constituting the grounds of the above formulas (1) and (2) will be explained.

The variables are defined below:

S total number of input digital signals (discrete signals)

L indexes 0, 1, ..., S-1 of digital signals

Y_org_L L-th organization digital signal (frequency domain expression)

y_org_L L-th organization digital signal (spatial domain expression)

Y_L L-th organization digital signal spatially shifted (frequency domain expression)

y_L L-th organization digital signal spatially shifted (spatial domain expression)

α_{xL} sampling phase difference (rad) in the x-axis direction with respect to 0th organization signal of L-th organization digital signal

α_{yL} sampling phase difference (rad) in the y-axis direction with respect to 0th organization signal of L-th organization digital signal

$X_{i,k}$ imaging components $X(\omega_x - i\cdot\omega_{sx},\ \omega_y - i\cdot\omega_{sy})$ of i-order in the x-direction and k-order in the y-direction, basic spectrum when i=k=0

P_x number of imaging components having negative order in the x-direction

Q_x number of imaging components having positive order in the x-direction

P_y number of imaging components having negative order in the y-direction

Q_y number of imaging components having positive order in the y-direction

N_x multiple indicating how many times of components with respect to Nyquist frequency were included in continuous signal input before being sampled in x-direction

M_x multiple indicating how many times of frequency components for restoration in the x-direction with respect to Nyquist frequency normally, $N_x=M_x$

N_y multiple indicating how many times of components with respect to Nyquist frequency were included in continuous signal input before being sampled in y-direction

M_x multiple indicating how many times of frequency components for restoration in the y-direction with respect to Nyquist frequency, normally, $N_y=M_y$

w_L complex number for multiplying with L-th

organization digital signal in frequency domain

A signal with sampling phase shifted by exactly α_x in the x-direction and α_y in the y-direction with respect to a reference discrete signal is, when indicating the reference discrete signal by the formula (4) below, indicated by the formula (5) below.

$$Y(\omega_x,\omega_y)=\sum_{i=-\infty}^{\infty}\sum_{k=-\infty}^{\infty}X(\omega_x-i\omega_{sx},\omega_y-k\omega_{sy}) \quad \ldots(4)$$

$$Y(\omega_X,\omega_Y)=\exp(j\cdot(\omega_X\alpha_X+\omega_Y-\alpha_Y)/2\pi)\cdot(\sum_{i=-\infty}^{\infty}\sum_{k=-\infty}^{\infty}\exp(-j\cdot(i\alpha_X+k\alpha_Y))X(\omega_X-i\omega_{SX},\omega_Y-k\omega_{SY}) \quad \ldots(5)$$

Here, two-dimensional spatial shift can be attained by shifting to a correct position after interpolation when in the spatial domain.

Also, when in the frequency domain, it is sufficient to multiply with "$\exp(-j(\omega x\cdot\alpha x+\omega y\cdot\alpha y)/(2\pi))$".

The spatial shift circuit can be realized for both the spatial domain and frequency domain.

For example, when performing two-dimensional spatial shift in the spatial domain, in Fig. 6, the Fourier transform circuit 51 and the spatial shift circuit 52 are switched. Namely, the Fourier transform is performed

after spatial shift.

Next, consider a complex number simultaneous equation for obtaining a complex number w_L to be multiplied with S number of discrete signals to reproduce basic spectrum components.

When in one dimension, the fact that the spectrum becomes symmetric between a positive frequency and a negative frequency based on the characteristics of a Fourier transform is used. It is sufficient to consider only a positive frequency and the number of imaging components in the positive range.

On the other hand, as in the present embodiment, when in two dimensions, due to the characteristics of a Fourier transform, conjugation occurs about the origin and not about the ωx-axis or ωy-axis. Namely, on a ωx-ωy plane, the first and third quadrants are conjugated and the second and the fourth quadrants are conjugated. Namely, the two quadrants next to each other, for example, the first quadrant and the second quadrant, are independent from each other. Accordingly, it is necessary to consider the imaging components included in two quadrants, for example, the first and second quadrants. Note that the remaining two quadrants can be obtained by using the conjugated relationship.

Thus, let us consider the first and the second

quadrants. First, consider the first quadrant. The number of discrete signals S necessary for obtaining solutions of a complex number simultaneous equation of the first quadrant becomes the product of the number of discrete signals necessary in the x-direction and the number of discrete signals necessary in the y-direction, that is, $S=(P_x+Q_x+1)\cdot(P_y+Q_y+1)$.

Here,

$P_x=\mathrm{FLoor}((N_x-1)/2)$

$Q_x=\mathrm{FLoor}((N_x+M_x-1)/2)$

$P_y=\mathrm{FLoor}((N_y-1)/2)$

$Q_y=\mathrm{FLoor}((N_y+M_y-1)/2)$

Note that in the present embodiment, when N_x, N_y, M_x, and M_y are all "2", S becomes "4". If obtaining four organizations of continuous signals, the imaging components can be removed and a signal up double the Nyquist frequency can be obtained.

Accordingly, the complex number simultaneous equation can be indicated as the formula (6) below when the number of formulas and the unknown number of the basic spectrum components $X_{0,0}$ and imaging components $X_{i,k}$ are S and the discrete signal of the first and the third quadrants after spatial shifting is assumed to be $Y13_{i,k}$. By solving the formula (6) below to obtain the complex number W_L, the basic spectrum components of the first and

the third quadrants can be obtained as shown in the formula (7) below. Note that W_L in the formula (7) below indicates a complex number.

$$Y13_L = \sum_{i=-Px,k}^{Qx} \sum_{k=-Py}^{Qy} esp(-j\cdot(i\alpha_{xL} + k\alpha_{yL}))X_{i,k}$$

where, L=0, 1, ..., S-1

...(6)

$$X13_{0,0} = \sum_{i=0}^{S-1} W_L Y13_L \qquad ...(7)$$

Next, if considering the second quadrant, ω_x is negative in the second quadrant and the imaging components in the x-direction also becomes a negative order. Therefore, the complex number simultaneous equation can be indicated as in the formula (9) below when assuming the number of formulas and the unknown number of basic spectrum components $X_{0,0}$ and imaging components $X_{i,k}$ to be S and assuming the discrete signals in the second and fourth quadrants after spatial shifting to be $Y24_L$. By solving the formula (8) below to obtain the complex number w_L', the basic spectrum components $X24_{0,0}$ can be obtained as shown in the formula (9) below.

Note that w_L' of the formula (9) below indicates a complex number different from w_L.

$$Y24_L = \sum_{i=-Qx}^{Px} \sum_{k=-Py}^{Qy} exp(-j \cdot (i\alpha_{xL} + k\alpha_{yL}))X_{i,k}$$

where L=0, 1, ..., S-1

...(8)

$$X24_{0,0} = \sum_{i=0}^{S-1} w_L{}'Y24_L \qquad ...(9)$$

The complex number w_L obtained from the above is used for removing the imaging components in the first and third quadrants, while the complex number w_L' is used for removing the imaging components in the second and the fourth quadrants.

Here, since the processing for removing the imaging components in the first and the third quadrants and the processing for removing the imaging components of the second and the fourth quadrants are independent, the signals are divided into two systems.

The processing for dividing the components into two systems generates a signal where the values of the second and fourth quadrants are replaced by "0" in the frequency domain and a signal where the values of the first and third quadrants are replaced by "0" in a frequency domain. On the other hand, when in a spatial domain, it generates a signal filtered for extracting the frequency

components of the second and the fourth quadrants and a signal filtered for extracting frequency components of the first and third quadrants.

Multiplying the complex numbers w_L and w_L' respectively with the two organizations of signals gives the basic spectrum $X13_L$ of the first and third quadrants wherein imaging components are removed and the basic spectrum $S24_L$ of the second and fourth quadrants wherein imaging components are removed.

Finally, the basic spectrum $X13_L$ and the basic spectrum $X24_L$ from which the imaging components have been removed may be added to obtain the desired band broadened signal.

This completes the explanation of the theory behind the band broadening method.

Below, the grounds of the above formulas (1) and (2) will be explained based on the above theory of the band broadening method.

Namely, a case where imaging components are removed from R data of pixels at positions shown in Fig. 4B, obtained from the image signal S5 of the four captured images, to broaden the band and R data of pixels at positions shown in Fig. 1C are generated will be explained.

Note that the case where imaging components are

removed from B data of pixels at positions shown in Fig. 4C, obtained from the image signal S5 of the four captured images, to broaden the band and B data of pixels at positions shown in Fig. 1D are generated is the same as the case of R data after removal of values of the sampling phase differences α_{xL}, and α_{yL}.

In the first and third quadrants, the formulas (10a) to (10d) are obtained from the above formula (6).

$$Y_0=X_{0,0}-jX_{1,0}+X_{0,1}-jX_{1,1} \quad \ldots(10a)$$

$$Y_1=X_{0,0}-X_{1,0}+jX_{0,1}-jX_{1,1} \quad \ldots(10b)$$

$$Y_2=X_{0,0}-jX_{1,0}-X_{0,1}+jX_{1,1} \quad \ldots(10c)$$

$$Y_3=X_{0,0}-X_{1,0}-jX_{0,1}+jX_{1,1} \quad \ldots(10d)$$

When solving the above formulas (10a) to (10d), the above formula (1) corresponding to the above formula (7) is introduced and the basic spectrum $X13_{0,0}$ of the first and third quadrants is obtained.

Regarding the second and fourth quadrants, the formulas (11a) to (11d) are obtained from the above formula (8).

$$Y_0=X_{0,0}+jX_{1,0}+X_{0,1}+jX_{1,1} \quad \ldots(11a)$$

$$Y_1=X_{0,0}-X_{1,0}+jX_{0,1}-jX_{1,1} \quad \ldots(11b)$$

$$Y_2=X_{0,0}+jX_{1,0}-X_{0,1}-jX_{1,1} \quad \ldots(11c)$$

$$Y_3=X_{0,0}-X_{1,0}-jX_{0,1}+jX_{1,1} \quad \text{...(11d)}$$

When solving the above formulas (11a) to (11d), the above formula (2) corresponding to the above formula (9) is derived and the basic spectrum $X24_{0,0}$ of the second and the fourth quadrants is obtained.

The inverse Fourier transform circuit 54 performs inverse Fourier transform on the image signal S53 input from the basic spectrum calculation circuit 53 to obtain a band broadened digital signal S8.

The camera signal processor 9, taking account of the correlation of the colors, generates an interpolated RGB signal or a luminance signal and a color difference signal from R, G, B data included in the image signal S8 from the signal processor 8.

Below, the operation of an electronic still camera of the present embodiment shown in Fig. 2 will be explained.

The CCD image sensor 4 moves in a predetermined direction by an exactly predetermined distance by being driven by the CCD drive 6. As shown in Fig. 3, it therefore captures four images having mutually different sampling phases and outputs received light signals $S4_0$ to $S4_3$ based on the captured four images to the AD converter 5.

Next, the AD converter 5 converts the received light signals $S4_0$ to $S4_3$ to digital image signals $S5_0$ to $S5_3$ and outputs them to the signal processor 8. The image signals $S5_0$ to $S5_3$ are stored in the memory 7, then read and processed in the signal processor 8.

In the signal processor 8, first, the interpolation circuit 50 interpolates the input image signals $S5_0$ to $S5_3$ and up-samples them two-fold to generate the image signals $S50_0$ to $S50_3$.

Then, the Fourier transform circuit 51 performs two-dimensional Fourier transform on the image signals S500 to S503 to generate the image signals S510 to S513 of the frequency domain expression.

Then, the spatial shift circuit 52 multiples the R data and B data of the image signals S510 to S513 with $\exp(-j(\omega_x \alpha_{x0} + \omega_y \alpha_{y0})/(2\pi))$ to $\exp(-j(\omega_x \alpha_{x3} + \omega_y \alpha_{y3})/(2\pi))$ to generate the image signals Y_0 to Y_3.

The basic spectrum calculation circuit 53 uses the input image signals Y_0 to Y_3 and the complex numbers stored in the memory 7 shown in Fig. 2 to separately generate an image signal S53 composed of a two-dimensional image signal $X_{0,0}$ of the R data and B data and outputs the image signal S53 comprised of the generated image signal $X_{0,0}$ of the R data and B data and the G data of the pixels at positions shown in Fig. 4A to

the inverse Fourier transform circuit 54.

The inverse Fourier transform circuit 54 performs an inverse Fourier transform on the input image signal S53 to broaden the band and generate a digital signal S8b.

The camera signal processor 9, taking account of the correlation of colors, processes the R, G, B data included in the image signal S8b to generate an interpolated RGB signal or a luminance signal and color difference signal.

Then, it outputs an image based on the generated RGB signal or the luminance signal and color difference signal.

As explained above, according to the electronic still camera of the present embodiment, it is possible to obtain a high definition image signal corresponding to double the numbers of pixels of the numbers of pixels of the CCD image sensor 4.

Also, according to the electronic still camera of the present embodiment, although the processing of the signal processor 8 becomes more complicated compared with that of the related art, as explained above, since it is not necessary to process the G data in the signal processor 8, the amount of data processing in the signal processor 8 can be reduced compared with a case where all the R, G and B data has to be processed.

Second Embodiment

Figure 7 is a view of a part of the configuration of an electronic still camera of the present embodiment.

As shown in Fig. 7, the electronic still camera of the present embodiment is the same as that of the above explained first embodiment except for the processing in a signal processor 68.

Figure 8 is a view of the configuration of the signal processor 68 shown in Fig. 7.

As shown in Fig. 8, the signal processor 68 comprises an interpolation circuit 70, a spatial shift circuit 71, and a broad band signal generation circuit 72.

The interpolation circuit 70 interpolates the image signals $S5_0$ to $S5_3$ of the four captured images having different sampling phases shown in Fig. 3 input from the AD converter 5 shown in Fig. 7 to generate the image signals $S70_0$ to $S70_3$.

The spatial shift circuit 71 shifts the image signals $S70_0$ to $S70_3$ input from the interpolation circuit 70 in the x-direction and y-direction by exactly the amount of the phase difference to generate image signals y_0 to y_3 in order to express the fact that the input image signals $S70_0$ to $S70_3$ were sampled at the positions in Figs. 4B and 4C.

Specifically, the spatial shift circuit 71 removes some samples from the top of the image signals $S70_0$ to $S70_3$ increased in the number of samples or adds some samples of appropriate values at the top to generate the signals y_0 to y_3.

The spatial shift circuit 71 outputs the signals y_0 to y_3 to the broad band signal generation circuit 72.

The broad band signal generation circuit 72 divides the image signals y_0 to y_3 to components wherein both x and y have positive frequencies and components wherein one of x and y has a negative frequency and the other has the opposite positive frequency. Namely, it applies two-dimensional filtering for taking out frequencies wherein both x and y are positive and a two-dimensional filter for taking out frequencies wherein one of x and y has a negative frequency and the other has the opposite positive frequency. The signals obtained in this way are $y13_L$ and $y24_L$.

The broad band signal generation circuit 72 applies two-dimensional Hilbert transform on the image signals $y13_L$ and $y24_L$. Namely, it shifts the phase by $\pi/2$(rad) by a not shown phase shifting means. The thus obtained signals are respectively called $y13_L'$ and $y24_L'$.

Then, the broad band signal generation circuit 72 uses real numbers indicating the real part and imaginary

part of the complex number w_L read from the memory 7 for $y13_L$ and processes $[Re(w_L) \cdot y13_L + Im(w_L) \cdot y13_L']$. In the same way, it uses the real numbers indicating the real part and imaginary part of the complex number w_L' read from the memory 7 for $y24_L$ and processes $[Re(w_L') \cdot y24_L + Im(w_L') \cdot y24_L']$.

Here, Re(x) indicates the real part and Im(x) indicates the imaginary part.

The broad band signal generation circuit 72 adds the results of $[Re(w_L) \cdot y13_L + Im(w_L) \cdot y13_L']$ and $[Re(w_L') \cdot y24_L + Im(w_L') \cdot y24_L']$ to cancel (remove) the aliasing to broaden the band and obtain the image signal S68.

Note that in the present embodiment, the real numbers indicating the real part and imaginary part of the complex numbers wL and wL' are stored in the memory 7 in advance.

The same effects can be obtained by the electronic still camera of the present embodiment as by the above explained electronic still camera of the first embodiment.

<u>Third Embodiment</u>

An electronic still camera of the present embodiment will be explained with reference to the case of using a CCD image sensor having a color compensating filter instead of a Bayer primary color filter array.

Figure 9 is a view of a part of the configuration of an electronic still camera of the present embodiment.

As shown in Fig. 9, the electronic still camera 1 comprises a lens 2, an optical LPF 3, a CCD image sensor 84, an AD converter 5, CCD drive 86, a memory 87, a signal processor 88, and a camera signal processor 9.

[CCD image sensor 84]

The CCD image sensor 84 comprises a plurality of photodiodes arranged in a matrix and a color compensation filter. The color compensation filter comprises filters transmitting Cy (cyan) color, M (magenta) color, Y (yellow), color and W (white) color arranged in the pattern shown in Fig. 10A. A photodiode receives light passing through the color compensation filter, converts the result from light to an electrical signal to generate received light signals S840 to S843 based on the amount of light received, and outputs the received light signals S84 to the AD converter 5.

The CCD image sensor 84, as will be explained later on, is driven to move by the CCD drive 86, captures four images having mutually different sampling phases, and generates received light signals $S84_0$ to $S84_3$ in order to obtain a high resolution image shown in Fig. 10B. At this time, the sampling phases of the four images may be any phases. In the present embodiment, for example as shown

in Fig. 10C, they are (0, 0), ($\pi/2$, 0), (0, $\pi/2$), and ($\pi/2$, $\pi/2$).

[AD converter 85]

The AD converter 85 converts the received light signals $S84_0$ to $S84_3$ to digital image signals $S85_0$ to $S85_3$ and outputs the image signals $S85_0$ to $S85_3$ to the signal processor 88.

[CCD drive 86]

The CCD drive 86 physically moves the CCD image sensor 84 in a predetermined direction by an exactly predetermined distance based on a control signal S88a from the signal processor 88 so as to give a sampling interval of the CCD image sensor 84 of 2π and so that the CCD image sensor 84 captures a total of four images having the four different sampling phases shown in Fig. 10C.

[Signal processor 88]

The signal processor 88 uses the image signals S850 to S853 of the four captured images having the mutually different sampling phases shown in Fig. 10C input from the AD converter 85 to generate an image signal S88b of an image wherein the numbers of pixels in the vertical and horizontal directions are doubled.

Also, the signal processor 88 generates a control signal S88a based on information regarding a direction of

movement and distance of the CCD image sensor 84 stored in the memory 87 in advance so that the four captured images having mutually different sampling phases shown in Fig. 10C can be obtained and outputs the control signal S88a to the CCD drive 86.

The signal processor 88 writes the image signals S850 to S853 of the four captured images of the pixel array pattern shown in Fig. 10A input from the AD converter 85 to the memory 87, then reads them and performs the later explained band broadening to generate an image signal S88b of a pixel array pattern shown in Fig. 10B.

Below, the processings for generating Cy data, Ye data, W data, and G data of the image signal S88b in the signal processor 88 will be explained.

Note that the processings for generating the Cy data, Ye data, W data, and G data are the same except for the values of the sampling phases.

Here, the sampling phase, as shown in Fig. 10C, has as its origin the position of a pixel outputting a color in accordance with the Cy data

Specifically, for the Cy data, the sampling phases of the four captured images, as shown in Fig. 10C, respectively become $(\alpha_{x0}, \alpha_{y0})=(0, 0)$, $(\alpha_{x1}, \alpha_{y1})=(\pi/2, 0)$, $(\alpha_{x2}, \alpha_{y2})=(\pi/2, \pi/2)$, and $(\alpha_{x3}, \alpha_{y3})=(0, \pi/2)$.

For the Ye data, the sampling phases of the four captured images respectively become $(\alpha_{x0}, \alpha_{y0})=(\pi/2, 0)$, $(\alpha_{x1}, \alpha_{y1})=(\pi, 0)$, $(\alpha_{x2}, \alpha_{y2})=(\pi/2, 0)$, and $(\alpha_{x3}, \alpha_{y3})=(\pi, \pi/2)$.

For the W data, the sampling phases of the four captured images respectively become $(\alpha_{x0}, \alpha_{y0})=(0, \pi/2)$, $(\alpha_{x1}, \alpha_{y1})=(\pi/2, \pi/2)$, $(\alpha_{x2}, \alpha_{y2})=(0, \pi/2)$, and $(\alpha_{x3}, \alpha_{y3})=(\pi/2, \pi)$.

For the G data, the sampling phases of the four captured images respectively become $(\alpha_{x0}, \alpha_{y0})=(\pi/2, \pi/2)$, $(\alpha_{x1}, \alpha_{y1})=(\pi, \pi/2)$, $(\alpha_{x2}, \alpha_{y2})=(\pi/2, \pi)$, and $(\alpha_{x3}, \alpha_{y3})=(\pi, \pi)$.

The values of these sampling phases are used as $(\alpha_{x0}, \alpha_{y0})$ to $(\alpha_{x3}, \alpha_{y3})$ at the time of the later explained spatial shifting and are stored in the memory 87 shown in Fig. 9 in advance.

Figure 11 is a view of the configuration of the signal processor 88.

As shown in Fig. 11, the signal processor 88 comprises an interpolation circuit 90, a Fourier transform circuit 91, a spatial shift circuit 92, a basic spectrum calculation circuit 93 and an inverse Fourier transform circuit 94.

The interpolation circuit 90 receives as inputs image signals $S85_0$ to $S85_3$, interpolates and up-samples

these two-fold to generate image signals $S90_0$ to $S90_3$, and outputs the image signals $S90_0$ to $S90_3$ to the Fourier transform circuit 91.

The Fourier transform circuit 91 performs a two-dimensional Fourier transform on the image signals $S90_0$ to $S90_3$ input from the interpolation circuit 90 to generate image signals $S91_0$ to $S91_3$ of the frequency domain expression and outputs the image signals $S91_0$ to $S91_3$ to the spatial shift circuit 92.

The spatial shift circuit 92 performs two-dimensional spatial shifting of the Cy data, Ye data, W data, and G data included in the image signals $S91_0$ to $S91_3$ obtained by the imaging to generate the image signals Y_0 to Y_3 in order to express that sampling was performed at the above explained positions $(\alpha_{x0}, \alpha_{y0})$ to $(\alpha_{x3}, \alpha_{y3})$.

Namely, the spatial shift circuit 92 multiplies the Cy data, Ye data, W data, and G data of the image signals $S91_0$ to $S91_3$ with $\exp(-j(\omega_x \alpha_{x0}+\omega_y \alpha_{y0})/(2\pi))$ to $\exp(-j(\omega_x \alpha_{x3}+\omega_y \alpha_{y3})/(2\pi))$, respectively, to generate the image signals Y_0 to Y_3.

Note, in this case, the portion higher than the Nyquist frequency indicates negative frequencies both in the x-direction and y-direction. ω_x or ω_y in that portion have to be made $(\omega_x-\omega_{sx})$ or $(\omega_y-\omega_{sy})$. Here, ω_{sx} and ω_{sy}

respectively are sampling frequencies in the x-direction and y-direction before up-sampling.

The basic spectrum calculation circuit 93 uses the image signals Y_0 to Y_3 input from the spatial shift circuit 92 and complex numbers stored in the memory 87 shown in Fig. 9 to separately generate two-dimensional image signals $X_{0,0}$ of the Cy data, Ye data, W data, and G data and outputs to the inverse Fourier transform circuit 94 an image signal S93 comprised by the generated image signals $X_{0,0}$ of the Cy data, Ye data, W data, and G data.

Note that the memory 87 stores, for the Cy data, Ye data, W data, and G data generated as will be explained later on, complex numbers w_0 to w_3 to be multiplied with the image signals Y_0 to Y_3 for obtaining the basic spectrum components $X13_{0,0}$ in the first and third quadrants and complex numbers w_0' to w_3' to be multiplied with the image signals Y_0 to Y_3 for obtaining the basic spectrum components $X24_{0,0}$ of the second and fourth quadrants.

The basic spectrum calculation circuit 93 obtains basic spectrum components $X13_{0,0}$ based on the formula (13) below obtained from the formulas (12a to 12d) below and obtains basic spectrum components $X24_{0,0}$ based on the formula (15) below obtained from the formulas (14a to 14d) below.

$$Y_0=X_{0,0}+X_{1,0}+X_{0,1}+X_{1,1} \quad \text{...(12a)}$$

$$Y_1=X_{0,0}-jX_{1,0}+X_{0,1}-jX_{1,1} \quad \text{...(12b)}$$

$$Y_2=X_{0,0}+X_{1,0}-jX_{0,1}+jX_{1,1} \quad \text{...(12c)}$$

$$Y_3=X_{0,0}-jX_{1,0}-jX_{0,1}-X_{1,1} \quad \text{...(12d)}$$

$$X13_{0,0}=\{-jY_0+Y_1+Y_2+jY_3\}/2 \quad \text{...(13)}$$

$$Y_0=X_{0,0}+X_{1,0}+X_{0,1}+X_{1,1} \quad \text{...(14a)}$$

$$Y_1=X_{0,0}+jX_{1,0}+X_{0,1}+jX_{1,1} \quad \text{...(14b)}$$

$$Y_2=X_{0,0}+X_{1,0}-jX_{0,1}-jX_{1,1} \quad \text{...(14c)}$$

$$Y_3=X_{0,0}+jX_{1,0}-jX_{0,1}+X_{1,1} \quad \text{...(14d)}$$

$$X24_{0,0}=\{Y_0-jY_1+jY_2+jY_3\}/2 \quad \text{...(15)}$$

Then, as shown in the formula (16) below, the basic spectrum components $X13_{0,0}$ and $X24_{0,0}$ are added to generate the basic spectrum components $X_{0,0}$.

$$X_{0,0}=X13_{0,0}+X24_{0,0} \quad \text{...(16)}$$

Also, the basic spectrum calculation circuit 93, in the same way as for the Cy data, obtains basic spectrum components $X13_{0,0}$ and basic spectrum components $X24_{0,0}$ for the Ye data, W data, and G data, and adds them to generate basic spectrum components $X_{0,0}$.

The inverse Fourier transform circuit 94 performs an inverse Fourier transform on the image signal S93 input from the basic spectrum calculation circuit 93 to broaden the band and obtain the digital signal S88b.

The camera signal processor 89 processes the Cy data, Ye data, W data, and G data included in the image signal S88b from the signal processor 88 to generate an interpolated RGB signal included or generate a luminance signal and color difference signal taking into account the correlation of the colors.

Next, the operation of the electronic still camera of the present embodiment shown in Fig. 9 will be explained.

The CCD image sensor 84 is driven by the CCD drive 86 to move in a predetermined direction by exactly a predetermined distance, captures four images having mutually different sampling phase as shown in Fig. 10C, and outputs the received light signals $S84_0$ to $S84_3$ based on the four captured images to the AD converter 85.

Next, the AD converter 85 converts the received light signals $S84_0$ to $S84_3$ to digital image signals $S85_0$ to $S85_3$ and output them to the signal processor 88. The image signals $S85_0$ to $S85_3$ are stored in the memory 87, then read and processed in the signal processor 88.

In the signal processor 88, first the interpolation

circuit 90 interpolates and up-samples two-fold the input image signals $S85_0$ to $S85_3$ to generate the image signals $S90_0$ to $S90_3$.

Then, the Fourier transform circuit 91 applies a two-dimensional Fourier transform to the image signals $S90_0$ to $S90_3$ to generate image signals $S91_0$ to $S91_3$ of the frequency domain expression.

Then, the spatial shift circuit 92 multiplies the Cy data, Ye data, W data, and G data of the image signals $S91_0$ to $S91_3$ with $\exp(-j(\omega_x \alpha_{x0} + \omega_y \alpha_{y0})/(2\Pi))$ to $\exp(-j(\omega_x \alpha_{x3} + \omega_y \alpha_{y3})/(2\Pi))$ to generate the image signals Y_0 to Y_3.

The basic spectrum calculation circuit 93 uses the input image signals Y_0 to Y_3 and the complex numbers stored in the memory 87 shown in Fig. 9 to separate generate two-dimensional image signals $X_{0,0}$ of the Cy data, Ye data, W data, and G data and outputs an image signal S93 comprised of the generated image signals $X_{0,0}$ of the Cy data, Ye data, W data, and G data to the inversed Fourier transform circuit 94.

The inverse Fourier transform circuit 94 applies an inverse Fourier transform to the input image signal S93 to broaden the band and generate the digital signal S88b.

The camera signal processor 89 processes the Cy data, Ye data, W data, and G data included in the image signal S88b to generate an interpolated RGB signal or

generate a luminance signal and color difference signal taking into account the correlation of the colors.

Then, it outputs an image in accordance with the generated RGB signal or the luminance signal and color difference signal.

As explained above, according to the electronic still camera of the present embodiment, even when using a CCD image sensor 84 having the above color compensation filter, a high definition image signal corresponding to double the number of pixels of the CCD image sensor 84 both in the vertical and horizontal directions can be obtained without complicated processing in the camera processor 89.

The present invention is not limited to the above embodiments.

For example, the orders of processing in the signal processor 8 shown in Fig. 2, the signal processor 68 shown in Fig. 7 and the signal processor 88 shown in Fig. 9 are not specifically limited to the above.

Also, the hardware configuration is not limited to that in Figs. 2, 7, and 9.

Also, in the present invention, processing in a spatial domain and processing in a frequency domain can be mixed together.

Furthermore, in the above embodiments, the CCD image

sensors 4 and 84 were physically moved to obtain four captured images having different sampling phase, however, a plurality of captured images having different sampling phases may be obtained by for example optically or electrically changing a light path by using a birefringent plate without physically moving the CCD image sensor.

Also, the values of the sampling phases are not limited to those described in the embodiments.

Also, a CCD image sensor was shown as an example of an imaging means in the above embodiments, however, a CMOS sensor etc. may also be used.

Also, in the above embodiments, a case where four captured images are used for obtaining a high resolution image (broadened band) doubled in the vertical and horizontal directions was shown as an example, but the increase in resolution is not particularly limited to two. Further, the increase in resolution may be different between the vertical direction and in the horizontal direction. Also, the band broadening may be not two dimensional, but also one dimensional.

Also, in the above embodiments, four captured images were used in order to obtain a high resolution image, however, the number of captured images used is not limited to four since it depends on the multiple in each

directions.

Also, the arrays of the colors of the color filters shown in Fig. 1A and Fig. 10A can be any arrays.

The phase shift means used in the spatial domain is not limited to the Hilbert transform and the amount of phase shift is not limited to $\pi/2$.

Summarizing the effect of the invention, as explained above, according to the signal processing apparatus and the method of the present invention, a signal can be broadened in band by simple processing.

Also, according to the image processing apparatus and the method of the present invention, a high resolution image can be obtained from a low resolution image by simple processing.

While the invention has been described with reference to specific embodiment chosen for purpose of illustration, it should be apparent that numerous modifications could be made thereto by those skilled in the art without departing from the basic concept and scope of the invention.

What is claimed is:

1. A signal processing apparatus, comprising:

a transforming means for transforming a plurality of first digital signals having mutually different sampling phases to a plurality of second digital signals in a frequency domain;

a memory means for storing a plurality of complex numbers corresponding to said sampling phases; and

a processing means for multiplying said plurality of second digital signals and said plurality of complex numbers corresponding to the plurality of second digital signals and adding the multiplied results to generate a third digital signal free from aliasing components.

2. A signal processing apparatus as set forth in claim 1, further comprising:

a phase shift means for shifting the phase of said first digital signals or said second digital signals by exactly a predetermined phase.

3. A signal processing apparatus, comprising:

a phase shift means for shifting the phase of a plurality of first digital signals having mutually different sampling phases to generate second digital signals;

a memory means for storing a plurality of real numbers indicating real parts and imaginary parts of a plurality of predetermined complex numbers corresponding to said sampling phases;

a processing means for multiplying said first digital signals with real numbers indicating said real parts corresponding to the first digital signals to obtain first multiplied results, multiplying said second digital signals corresponding to said first digital signals with real numbers indicating said imaginary parts corresponding to the second digital signals to obtain second multiplied results, and adding said first multiplied results and said second multiplied results to generate third digital signals free of aliasing components.

4. An image processing apparatus, comprising:

an image input means for generating a plurality of first image signals having mutually different sampling phases in accordance with imaging results;

a transforming means for transforming the first image signals to a plurality of second image signals in a frequency domain;

a memory means for storing a plurality of complex numbers corresponding to said sampling phases;

a processing means for multiplying said

plurality of second image signals with said plurality of complex numbers corresponding to the plurality of second image signals and adding the multiplied results to generate third image signals free from aliasing components.

5. An image processing apparatus as set forth in claim 4, wherein:

said image input means forms an image of a plurality of color lights passed through a single-plate type color filter on corresponding pixels among a plurality of pixels arranged in a matrix two-dimensionally to generate said first image signals comprised by color data of said plurality of colors; and

said processing means performs said multiplication and said addition for every color data of said plurality of color data to generate a plurality of fourth image signals corresponding to said plurality of colors and generates said third image signals by using the plurality of fourth image signals.

6. An image processing apparatus as set forth in claim 5, wherein:

said sampling phase is determined for a predetermined one color among said plurality of colors in order that a sampling pattern of color data of the color included in said plurality of first image signals and a

sampling pattern of color data included in said fourth image signals of the color become similar.

7. An image processing apparatus as set forth in claim 4, wherein said processing means comprises:

a spatial shift means for spatially shifting said second image signals in accordance with said sampling phases;

a basic spectrum calculation means for multiplying said spatially shifted plurality of second image signals with said plurality of complex numbers corresponding to said plurality of second image signals and adding the multiplied results to calculate a basic spectrum free from aliasing components; and

an inverse transforming means for transforming said basic spectrum from a frequency domain to a time domain to generate said third image signals.

8. An image processing apparatus as set forth in claim 4, further comprising:

a drive means for moving said image input means physically, optically, or electrically so that said imaging means can generate a plurality of image signals having mutually different sampling phases in accordance with the imaging results.

9. An image processing apparatus as set forth in claim 5, wherein:

said image input means is a single-element CCD image sensor and

said color filter is a primary color filter or a color compensation filter.

10. An image processing apparatus, comprising:

an image input means for receiving as input a plurality of first image signals having mutually different sampling phases in accordance with imaging results;

a phase shift means for shifting the phase of said plurality of first digital signals to generate second digital signals;

a memory means for storing a plurality of real numbers respectively indicating real parts and imaginary parts of a plurality of predetermined complex numbers corresponding to said sampling phases;

a processing means for multiplying said first digital signals with real numbers indicating said real parts corresponding to the first digital signals to obtain first multiplied results, multiplying said second digital signals corresponding to said first digital signals with real numbers indicating said imaginary parts corresponding to the second digital signals to obtain second multiplied results, and adding said first multiplied results and said second multiplied results to

generate third digital signals free from aliasing components.

11. A signal processing method comprising the steps of:

transforming a plurality of first digital signals having mutually different sampling phases to domain a plurality of second digital signals in a frequency domain;

multiplying said plurality of second digital signals with a plurality of complex numbers corresponding to the plurality of second digital signals; and

adding the multiplied results to generate third digital signals free from aliasing components.

12. A signal processing method using a plurality of real numbers indicating real parts and imaginary parts of a predetermined plurality of complex numbers corresponding to sampling phases, comprising the steps of:

shifting a plurality of first digital signals having mutually different sampling phases by predetermined phases to generate second digital signals;

multiplying said first digital signals with real numbers indicating said real parts corresponding to the first digital signals to generate first multiplied results;

multiplying said second digital signals corresponding to said first digital signals with real numbers indicating said imaginary parts corresponding to the second digital signal to generate second multiplied results; and

adding said first multiplied results and said second multiplied results to generate third digital signals free of aliasing components.

13. An image processing method comprising the steps of:

generating a plurality of first image signals having mutually different sampling phases in accordance with imaging results;

transforming the first image signals to a plurality of second image signals in a frequency domain; and

multiplying said plurality of second image signals with a plurality of complex numbers corresponding to the plurality of second image signals and adding the multiplied results to generate third image signals free from aliasing components.

14. An image processing method as set forth in claim 13, further comprising the steps of:

forming an image of a plurality of color lights passing through a single-plate type color filter on

corresponding pixels among a plurality of pixels arranged in a matrix two-dimensionally to generate said first image signals comprised by color data of said plurality of colors and

performing said multiplication and said addition for every color data of said plurality of colors to generate a plurality of fourth image signals corresponding to said plurality of colors and generate said third image signals by using the plurality of fourth image signals.

15. An image processing method as set forth in claim 14, further comprising the steps of determining said sampling phase for a predetermined one color among said plurality of colors so that a sampling pattern of color data of the color included in said plurality of first image signals and a sampling pattern of color data included in said fourth image signals of the color become similar.

16. An image processing method using a plurality of real numbers prepared in advance indicating real parts and imaginary parts of a predetermined plurality of complex numbers corresponding to sampling phases, comprising the steps of:

generating a plurality of first image signals having mutually different sampling phases in accordance

with imaging results;

shifting by a predetermined phase said plurality of first digital signals to generate second digital signals;

multiplying said first digital signals with real numbers indicating said real parts corresponding to the first digital signals to generate first multiplied results;

multiplying said second digital signals corresponding to said first digital signals with real numbers indicating said imaginary parts corresponding to the second digital signals to generate second multiplied results; and

adding said first multiplied results and said second multiplied results to generate third digital signals free from aliasing components.

SIGNAL PROCESSING APPARATUS, METHOD OF THE SAME, AN IMAGE PROCESSING APPARATUS AND METHOD OF THE SAME

ABSTRACT OF THE DISCLOSURE

An image processing apparatus capable of obtaining a high resolution image from a low resolution image without making processing in a camera signal processor complicated, wherein a CCD image sensor is moved by a CCD drive and a plurality of received light signals having mutually different sampling phases are generated in accordance with imaging results in the CCD image sensor, the received light signals are converted to image signals in an AD converter, the image signals are transformed to a frequency domain signal in a signal processor and multiplied with a plurality of respectively corresponding complex numbers stored in a memory, and the multiplied results are added to generate an image signal free from aliasing components.

FIG.1A

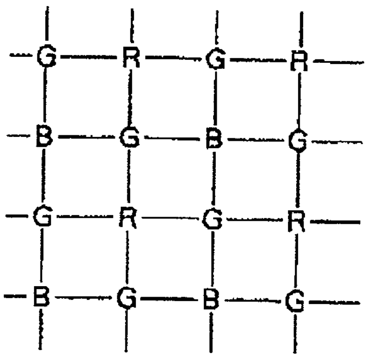


FIG.1B

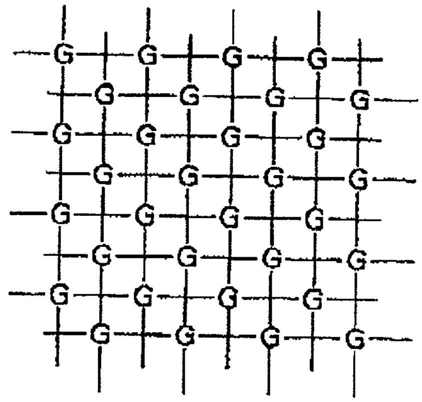


FIG.1C

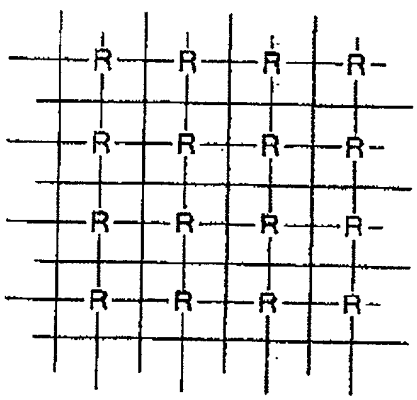


FIG.1D

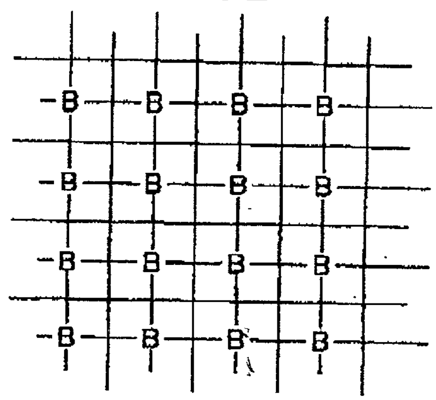


FIG.1E

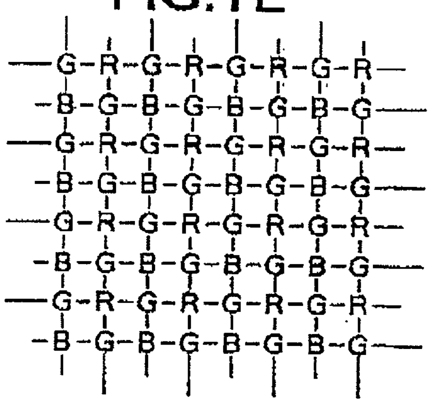


FIG.2

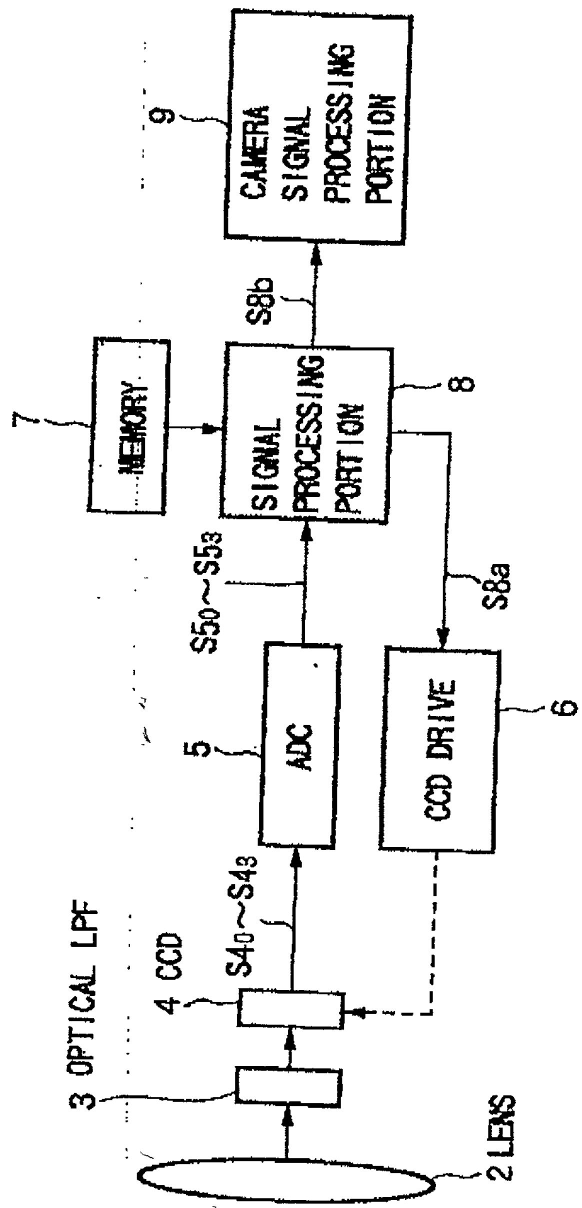

2 LENS
3 OPTICAL LPF
4 CCD
$S4_0 \sim S4_3$
5
ADC
$S5_0 \sim S5_3$
6
CCD DRIVE
7
MEMORY
8
SIGNAL PROCESSING PORTION
S8a
S8b
9
CAMERA SIGNAL PROCESSING PORTION

FIG.3

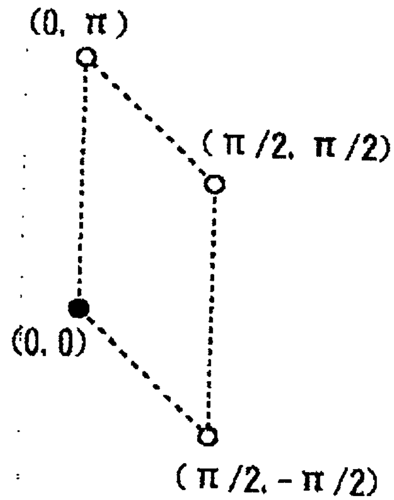


FIG.4A

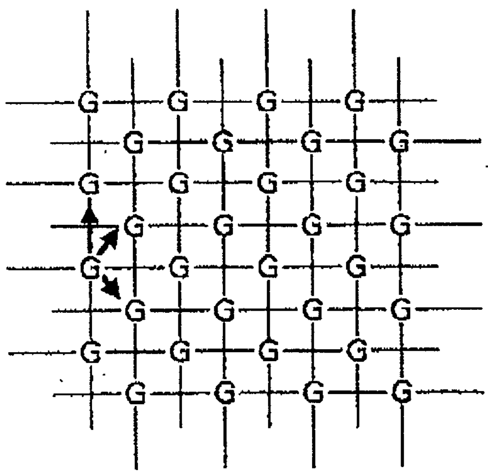


FIG.4B

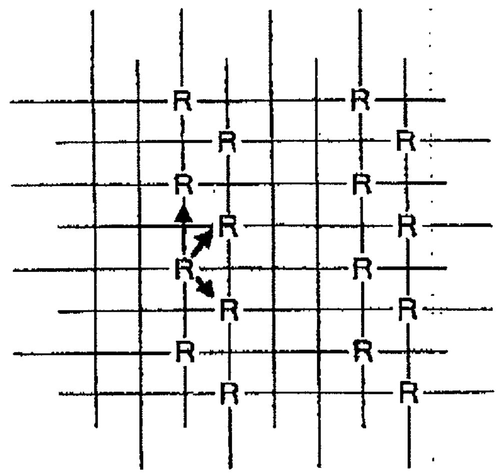


FIG.4C

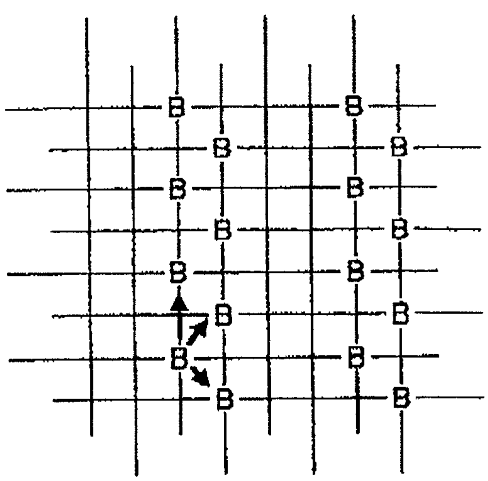


FIG.5A

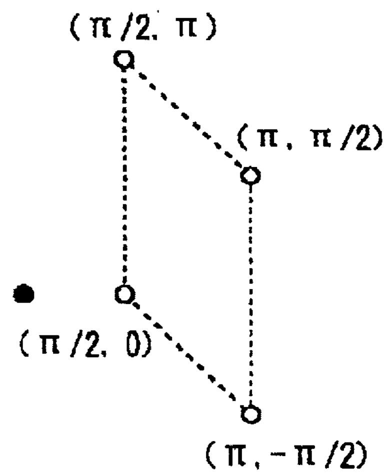


FIG.5B

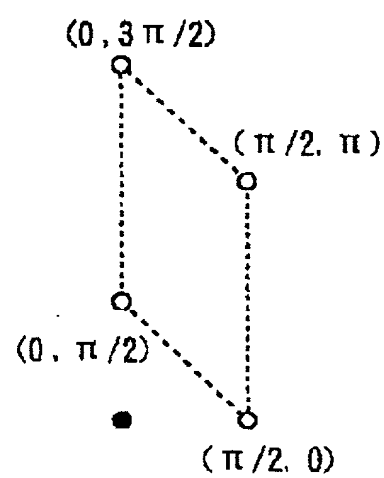
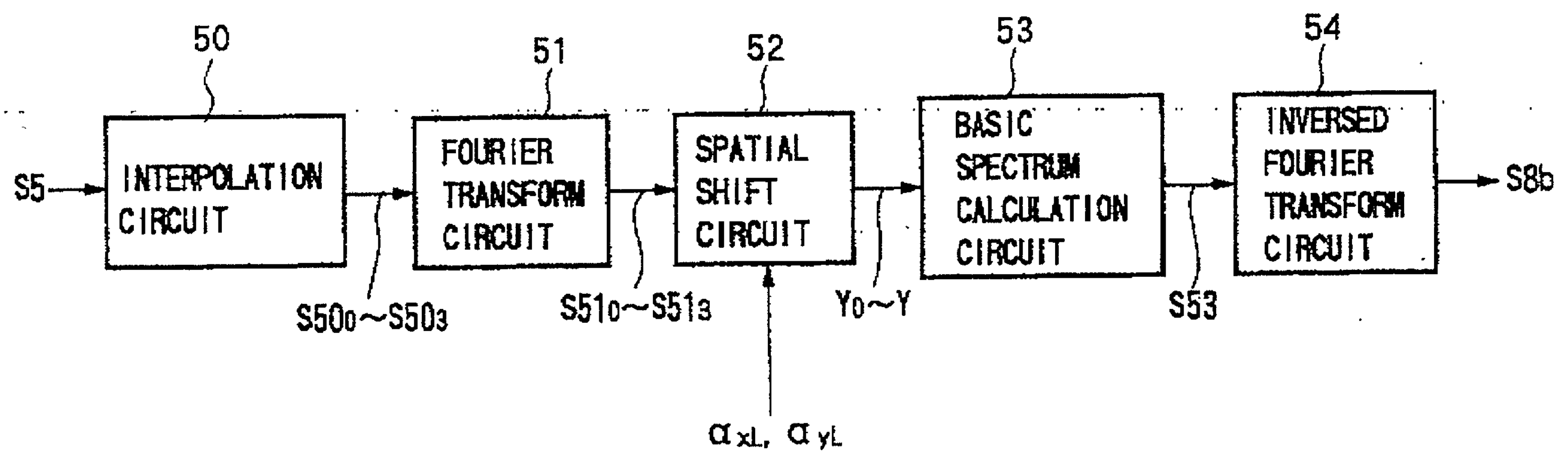
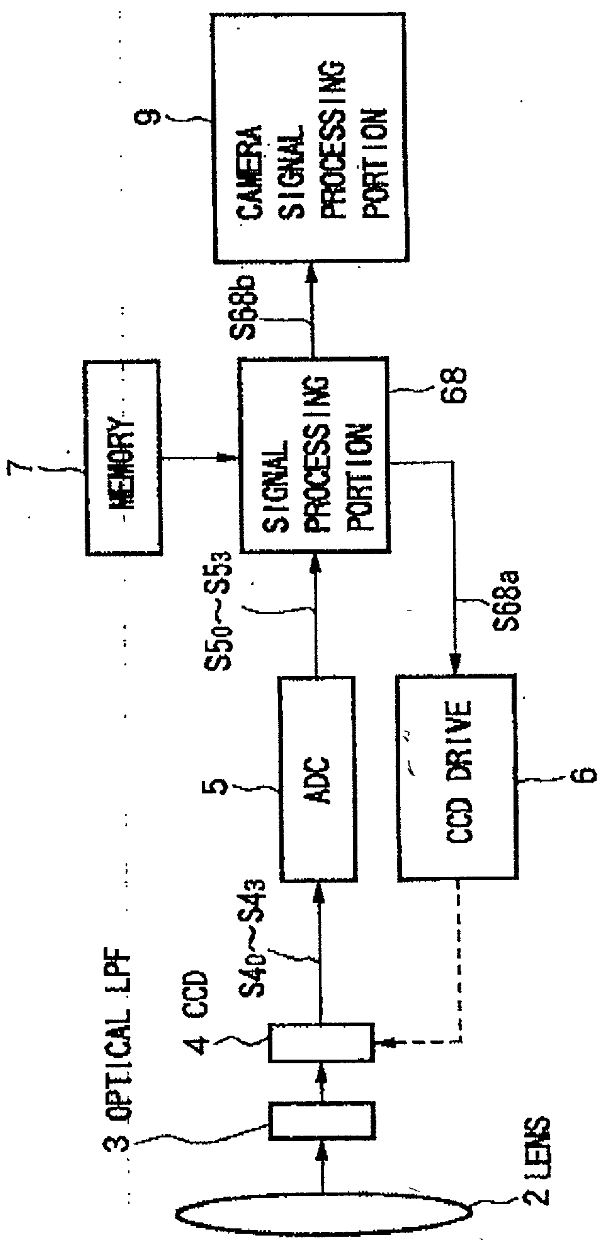


FIG.6



8 SIGNAL PROCESSING PORTION



CAMERA SIGNAL PROCESSING PORTION
9
S68b
MEMORY
7
SIGNAL PROCESSING PORTION
68
S50~S53
S68a
ADC
5
CCD DRIVE
6
S40~S43
4 CCD
3 OPTICAL LPF
2 LENS

FIG.7

FIG.8

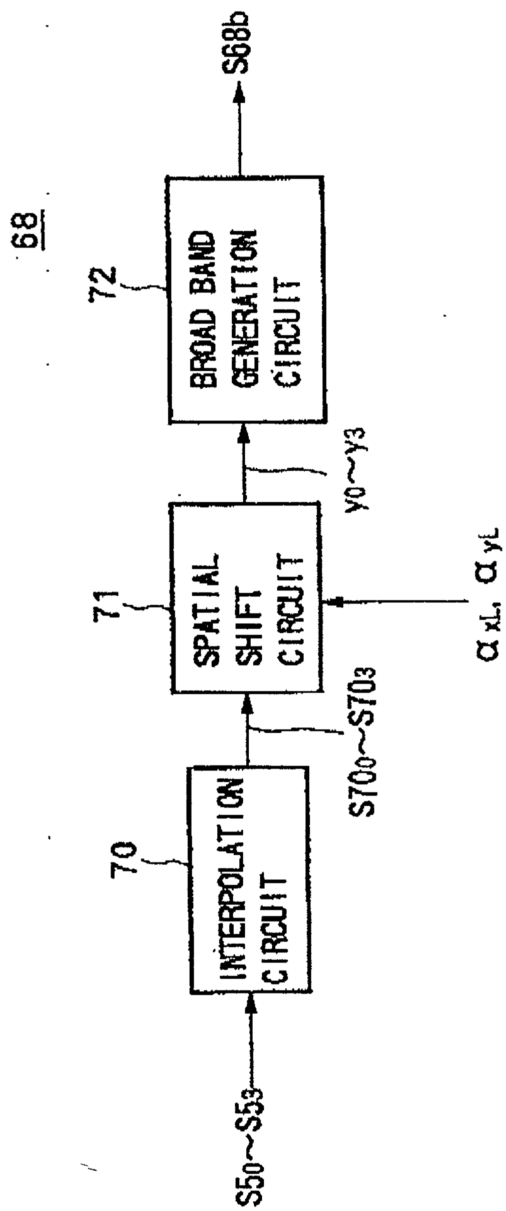

68
$S5_0 \sim S5_3$
70
INTERPOLATION CIRCUIT
$S70_0 \sim S70_3$
71
SPATIAL SHIFT CIRCUIT
α_{xL}, α_{yL}
$Y0 \sim Y3$
72
BROAD BAND GENERATION CIRCUIT
S68b

FIG.9

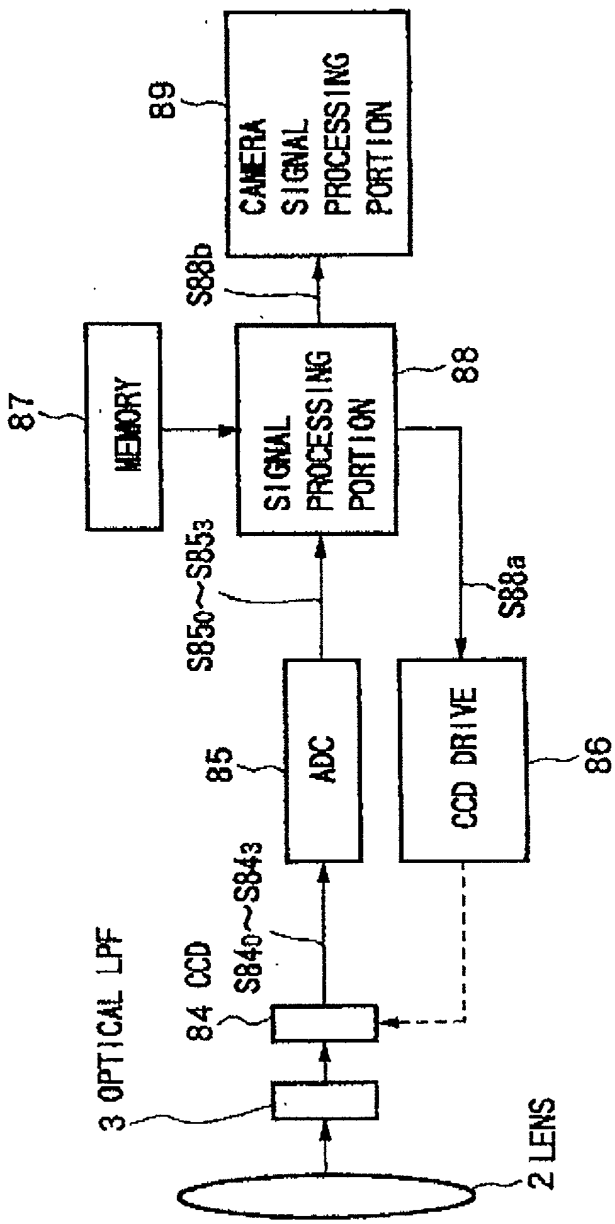

CAMERA SIGNAL PROCESSING PORTION
89
S88b
MEMORY
87
SIGNAL PROCESSING PORTION
88
S85₀~S85₃
S88a
ADC
85
CCD DRIVE
86
S84₀~S84₃
84 CCD
3 OPTICAL LPF
2 LENS

FIG.10A

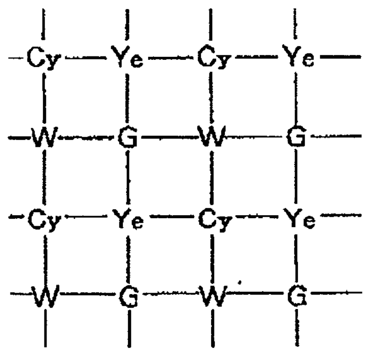


FIG.10A

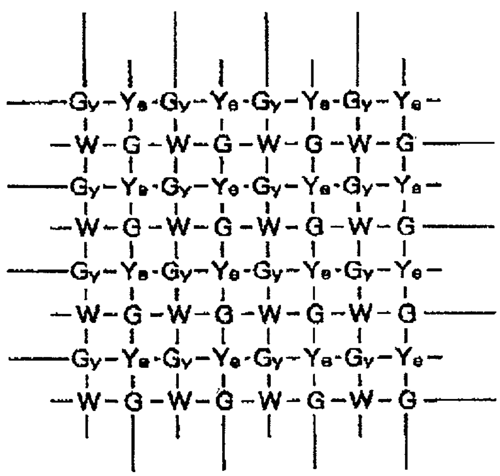


FIG.10C

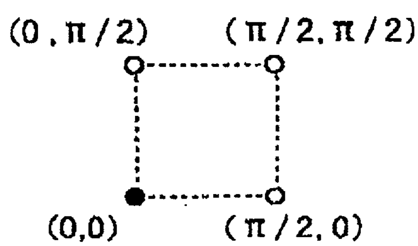
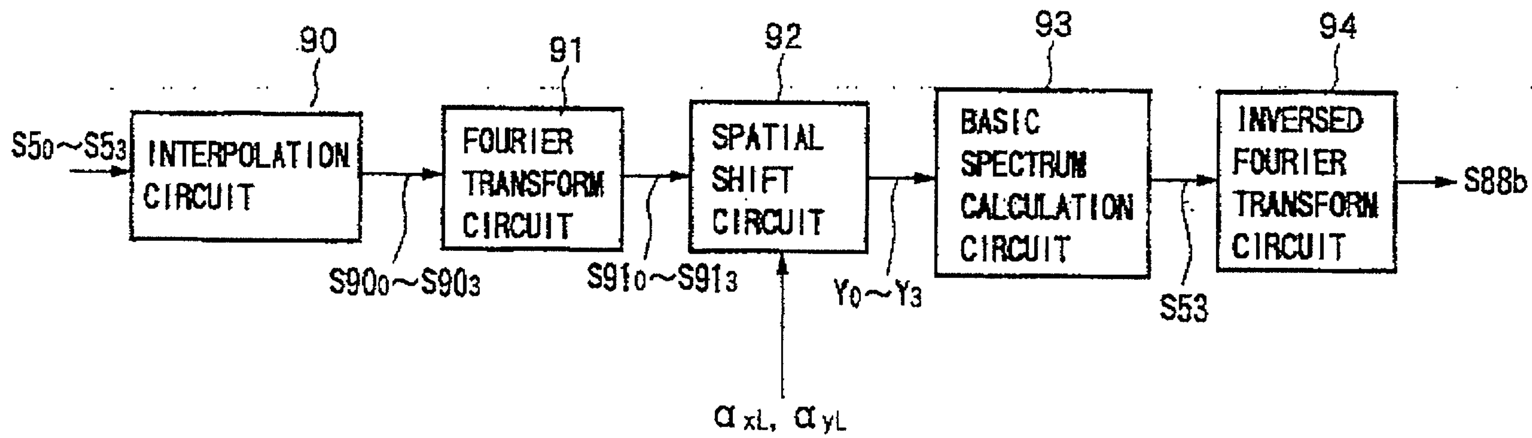


FIG.11



88 SIGNAL PROCESSING PORTION

FIG.12A

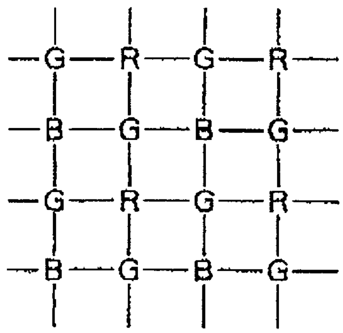


FIG.12B

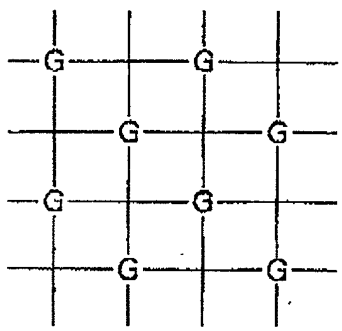


FIG.12C

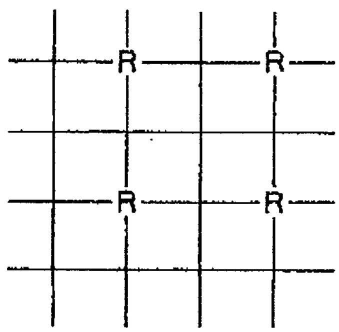


FIG.12D

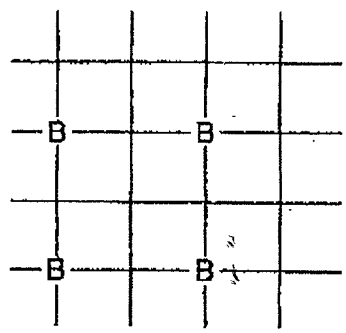


FIG.12E

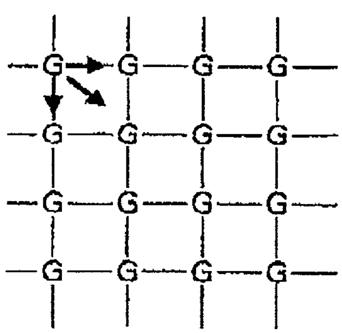


FIG.12F

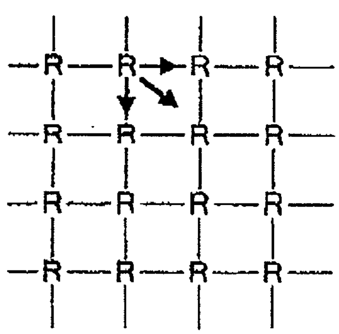
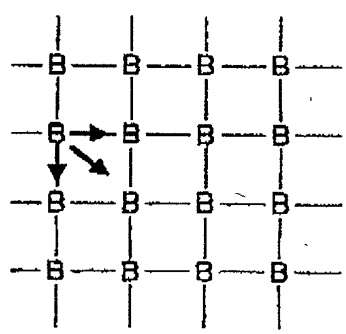


FIG.12F



BY EXPRESS MAIL NO. EL059097980US
Attorney Docket No. SONY-T0665

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of	)	Group Art Unit: Unknown
SHIRO OMORI ET AL.	)	Examiner: Unknown
Application No. Not Assigned	)	LETTER TO OFFICIAL DRAFTSPERSON
Filed: Herewith	)	2001 Ferry Bldg. San Francisco, CA 94111 Ph.: 415-433-4150
For: SIGNAL PROCESSING APPARATUS, METHOD OF THE SAME, AN IMAGE PROCESSING APPARATUS AND METHOD OF THE SAME	)	

Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

With the permission of the Examiner, please amend the drawings as described below and shown and in the attached redlined drawings:

Please relabel the lowermost "FIG.10A" as --FIG.10B--.

Please relabel the rightmost "FIG.12F" as --FIG.12G--.

Respectfully submitted,

LIMBACH & LIMBACH L.L.P.

By: ______________________
Charles P. Sammut
Reg. No. 28,901

June 1, 2000
Our File: SONY-T0665

FIG.10A

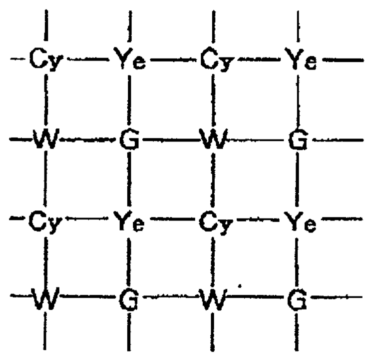


FIG.10B
~~FIG.10A~~

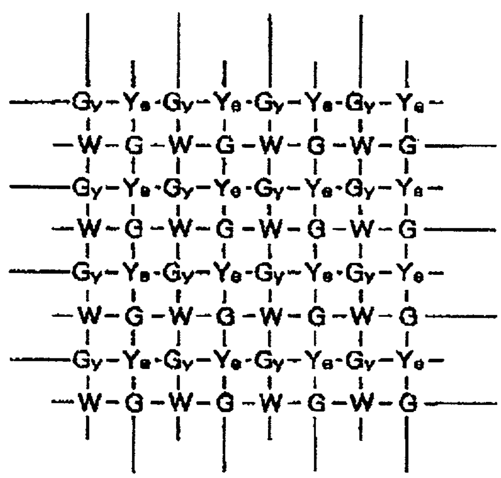


FIG.10C

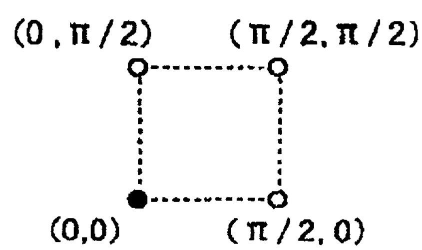


FIG.12A

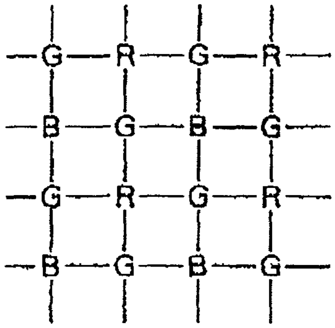


FIG.12B

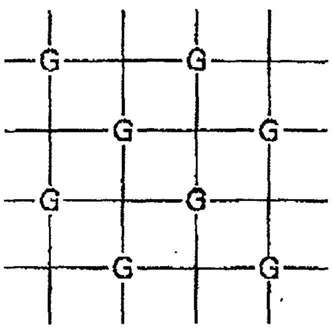


FIG.12C

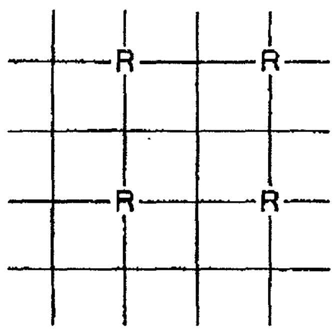


FIG.12D

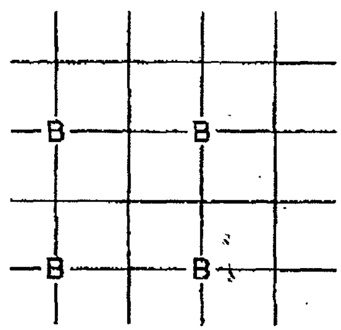


FIG.12E

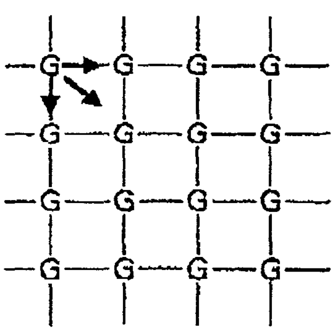


FIG.12F

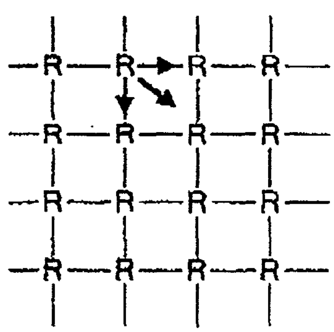
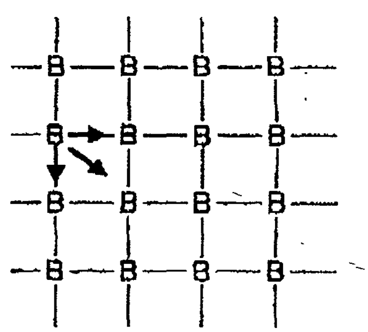


FIG.12G

~~FIG.12F~~



SONY-T0665

BY EXPRESS MAIL NO. EL059097980US

Declaration and Power of Attorney For Patent Application
特許出願宣言書及び委任状

Japanese Language Declaration
日本語宣言書

下記の氏名の発明者として、私は以下の通り宣言します。	As a below named inventor, I hereby declare that:
私の住所、私書箱、国籍は下記の私の氏名の後に記載された通りです。	My residence, post office address and citizenship are as stated next to my name.
下記の名称の発明に関して請求範囲に記載され、特許出願している発明内容について、私が最初かつ唯一の発明者（下記の氏名が一つの場合）もしくは最初かつ共同発明者であると（下記の名称が複数の場合）信じています。 ______ ______	I believe I am the original, first and sole inventor (if only one named is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled. SIGNAL PROCESSING APPARATUS, METHOD OF THE SAME, AN IMAGE PROCESSING APPARATUS AND METHOD OF THE SAME
上記発明の明細書（下記の欄でx印がついていない場合は、本書に添付）は、 ☐ __月__日に提出され、米国出願番号または特許協定条約国際出願番号を__________とし、（該当する場合）__________ に訂正されました。	the specification of which is attached hereto unless the following box is checked: ☐ was filed on ____ as United States Application Number or PCT International Application Number ____ and was amended on _____ (if applicable).
私は、特許請求範囲を含む上記訂正後の明細書を検討し、内容を理解していることをここに表明します。	I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.
私は、連邦規則法典第３７編第１条５６項に定義されるとおり、特許資格の有無について重要な情報を開示する義務があることを認めます。	I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56.
私は、米国法典第３５編１１９条 (a) - (d) 項又は３６５条 (b) 項に基き下記の、米国以外の国の少なくとも一ヵ国を指定している特許協力条約３６５(a)項に基ずく国際出願、又は外国での特許出願もしくは発明者証の出願についての外国優先権をここに主張するとともに、優先権を主張している、本出願の前に出願された特許または発明者証の外国出願を以下に、枠内をマークすることで、示しています。	I hereby claim foreign priority under Title 35, United States Code, Section 119(a)-(d) or 365(b) of any foreign application(s) for patent or inventor's certificate, or 365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or PCT International application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application(s)
外国での先行出願

P11-157431	Japan	4 June 1999	____
(Number) (番号)	(Country) (国名)	(Day/Month/Year Filed) (出願年月日)	Priority Not Claimed 優先権主張なし

Japanese Language Declaration
日本語宣言書

(Number) (番号) ／ (Country) (国名)	(Day/Month/Year Filed) (出願年月日)
私は、第３５編米国法典１１９条(e)項に基いて下記の米国特許出願規定に記載された権利をここに主張いたします。	I hereby claim the benefit under Title 35, United States Code, Section 119(e) of any United States provisional application(s) listed below.
(Application No.) (出願番号) ／ (Filing Date) (出願日)	(Application No.) (出願番号 ／ (Filing Date) (出願日)
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(Application No.) (出願番号) ／ (Filing Date) (出願日)	(Status: Patented, Pending, Abandoned) (現況：特許許可済、係属中、放棄済)
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Japanese Language Declaration
日本語宣言書

委任状： 私は下記の発明者として、本出願に関する一切の手続きを米特許商標局に対して遂行する弁理士または代理人として、下記の者を指名いたします。（弁護士、または代理人の氏名及び登録番号を明記のこと）	POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark office connected therewith (*list name and registration number*)

Karl A. Limbach	18,689	Steven M. Everett	30,050	Cameron A King	41,897
George C. Limbach	19,305	Alfred A Equitz	30,922	Kyla L Harriel	41,815
John K. Uilkema	20,282	Charles P. Sammut	28,901	Mayumi Maeda	40,075
Neil A. Smith	25,441	Mark C. Pickering	36,239	Michael R. Ward	38,651
Veronica C Devitt	29,375	Patricia Coleman James	37,155	Roger S Sampson	44,314
Ronald L. Yin	27,607	Kathleen A. Frost	37,326	Charles L. Hamilton	42,624
Gerald T. Sekimura	30,103	Alan A. Limbach	39,749	Andrew V. Smith	43,132
Michael A. Stallman	29,444	Douglas C. Limbach	35,249	Eric N. Hoover	37,355
Philip A. Girard	28,848	Seong-Kun Oh*		J. Thomas McCarthy	22,420
Michael J Pollock	29,098	* Recognition under 37 CFR 10 9(b)		Joel G. Ackerman	24,307

書類送付先	Send Correspondence to: **Charles P. Sammut, Esq.** **Limbach & Limbach L.L.P.** **2001 Ferry Building** **San Francisco, CA 94111-4262**
直接電話連絡先：（名前及び電話番号）	Direct Telephone Calls to: (*name and telephone number*) **Charles P. Sammut** **(415) 433-4150**
唯一または第一発明者名	Full name of sole or first inventor: SHIRO OMORI
発明者の署名　　日付	Inventor's signature　　Date
住所	Residence Kanagawa, Japan
国籍	Citizenship Japan
私書箱	Post Office Address c/o SONY CORPORATION 7-35, Kitashinagawa 6-chome Shinagawa-ku, Tokyo, 141-0001 JAPAN

Japanese Language Declaration 日本語宣言書	
第二共同発明者	Full name of second joint inventor, if any KAZUHIKO UEDA
第二共同発明者 日付	Second inventor's signature Date
住所	Residence Kanagawa, Japan
国籍	Citizenship Japan
私書箱	Post Office Address c/o SONY CORPORATION 7-35, Kitashinagawa 6-chome Shinagawa-ku, Tokyo, 141-0001 JAPAN